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Description

Encapsulation of a magnetic resonance tomography device for attenuation of low sound frequencies

The present invention relates generally to magnetic resonance tomography (MRT) used in medicine to examine patients. The present invention relates especially to a magnetic resonance tomography device, wherein vibrations of device components especially in the low frequency range are attenuated by a novel encapsulation of the MRT device.

MRT is based on the physical phenomenon of nuclear spin and has been used successfully as an imaging method in medicine and biophysics for more than 15 years. With this examination method the subject is exposed to a powerful and constant magnetic field. As a result the previously random nuclear spin of the atoms in the subject is thereby aligned. High-frequency waves can now stimulate this "ordered" nuclear spin to a specific vibration. This vibration generates the actual measurement signal in MRT and this is detected by suitable receiver coils. The use of non-homogenous magnet fields, generated by gradient coils, means that the measurement object can be spatially coded in all three spatial directions. The method allows free selection of the layer to be imaged, so sectional images of the human body can be recorded in all directions. MRT as a sectional imaging method in medical diagnostics is primarily characterized as a non-invasive examination method by a versatile contrast capability. MRT currently uses applications with a high gradient capacity, which allow excellent imaging quality at measurement times of seconds and minutes.

The constant technical development of the components of MRT devices and the introduction of faster imaging sequences have opened up an increasing number of areas of use for MRT in medicine. Real-time imaging to assist with minimally invasive surgery, functional imaging in neurology and perfusion measurement in cardiology are just a few examples.

Figure 8 shows a schematic section through an MRT device according to the prior art. The section shows further components of the inner area enclosed by the basic field magnet 1. The basic field magnet 1 contains superconducting magnet coils in liquid helium and is surrounded by a magnet shell 12 in the form of a twin-shell tank. The so-called cold head 15 outside the magnet shell 12 is responsible for keeping the temperature constant. In the inner area enclosed by the magnet shell 12 (also referred to as the magnet vessel) the gradient coil 2 is suspended concentrically by means of carrier elements 7. The high-frequency resonator 13 is also inserted concentrically inside the gradient coil 2. The high-frequency resonator 13 has the task of converting the HF pulses emitted by a power transmitter to a magnetic alternating field to stimulate the atomic nuclei of the patient 18 and then to convert the alternating field from the preceding nuclear moment to a voltage fed to the receiver link. The upper section of the high-frequency resonator 13 is connected mechanically via cladding 29 to the magnet shell 12. So-called tongues 30 are mounted in a contiguous manner on the lower section of the high-frequency resonator 13 by means of which the high-frequency resonator 13 is in turn connected mechanically via cladding 29 and by means of carrier elements 7 to the lower section of the magnet shell 12. The patient 18 is inserted on a stretcher 19 on top of slide rails 17 arranged on the tongues 30 and the HF resonator 13 (together referred to as a body coil) into the opening or inner area of the system. The stretcher is placed on a vertically adjustable support frame 16.

The essential structure of the basic field magnet is shown perspectively in Figure 9. It shows the basic field magnet 1 (e.g. an axial superconducting air coil magnet with active leakage field screening) that generates a homogenous magnetic basic field in an inner area. The superconducting magnet 1 internally comprises superconducting coils in liquid helium. The basic field magnet is surrounded by a twin-shell tank, generally made of high-grade steel. The inner tank containing the liquid helium, which also partly serves as a winding body for the magnet coils, is suspended by means of glass fiber reinforced plastic rods with low heat conductivity from the outer tank, which is at room temperature. There is a vacuum between the inner and outer tanks.

The cylindrical gradient coil 2 is inserted concentrically into the inner area of the basic field magnet 1 by means of carrier elements 7. The body coil 13 is also concentrically inserted therein.

The gradient coil 2 has two part-windings, which generate a gradient field spatially perpendicular to each other and proportional to the injected current in each instance. As shown in Figure 10, the gradient coil 2 comprises an x-coil 3, a y-coil 4 and a z-coil 5, each of which is wound round the coil core 6, thereby generating a gradient field expediently in the direction of the Cartesian coordinates x, y and z. Each of these coils is equipped with its own power supply in order to generate independent current pulses at the correct amplitude and time according to the sequence programmed in the pulse sequence controller. The currents required are around 250 A. As the gradient switching times should be as short as possible, current increase rates of around 250 kA/s are required. In an extraordinarily powerful magnet field, as generated by the basic field magnet 1 (typically between 0.22 to 1.5 tesla), such switching processes are associated with significant mechanical vibration due to the Lorentz forces

occurring. All system components linked mechanically to the gradient system (housing, covers, basic field magnet tank or magnet shell, body coil BC, etc.) are stimulated to forced vibration.

As the gradient coil is generally surrounded by conductive structures (e.g. high-grade steel magnet shell, conductive copper surfaces of the HF resonator), the pulsed fields trigger eddy currents therein, which interact with the basic magnet field to exert forces on said structures and also stimulate said structures to vibrate.

A further vibration source, which primarily causes the magnet vessel to vibrate, is the so-called cold head 6, which ensures that the temperature of the basic field magnet 1 is maintained. It is driven by a compressor and subjects the shell of the basic field magnet 1 to mechanical impact.

Said vibration of the different MR components has a negative effect on the MR system in many ways:

1. An extremely high level of air-borne noise is generated, which is disturbing for the patient, the operating personnel and other people in the vicinity of the MR device.
2. The vibration of the gradient coil and the basic field magnet and the transmission of said vibration to the HF resonator in the inner area of the basic field magnet or the gradient coil is manifested in inadequate clinical image quality, which can even result in misdiagnosis (e.g. with functional imaging fMRI).
3. If the vibration of the magnet shell - i.e. the outer tank - is transmitted via the glass fiber reinforced plastic rods to the inner tank or the superconductor itself is stimulated to vibrate, a higher level of helium evaporation takes place -

as with an ultrasonic atomizer - thereby incurring higher costs.

As already mentioned, most vibration or most noise originates in some way from the gradient coils (GC). The noise generated by the cold head is only 70 to 80 dB compared with 120 dB by the gradient coil, which transmits this much higher value in different ways to the magnet shell and HF resonator.

To prevent transmission of the noise to the HF resonator or the copper eddy current surfaces representing such, various measures have already been taken:
Firstly the large surfaces of the copper film hitherto inserted relatively loosely in a carrier tube with a paper lattice structure were significantly reduced by "slots". Secondly said films were connected rigidly and permanently to the carrier tube so that only vibration of the carrier tube could also result in vibration of the copper conductive surfaces. Thirdly vibration of the carrier tube was impeded by significantly increasing the mass of the carrier tube using other materials.

Despite these modifications further noise transmission still occurs from the gradient coil to the HF resonator and also to the magnet shell. There are essentially three transmission mechanisms, which are outlined below:

I. Switching the gradient coil causes eddy currents to be generated both in the magnet shell and in the HF resonator and the Lorentz forces of said eddy currents as before cause vibration in the magnet shell.
II. The gradient coil and HF resonator or magnet shell and gradient coil respectively represent two cylinders, one inside the other, the radial distance of which - in the

form of an air gap - between magnet and GC is approx. 1 cm and between GC and body coil only approx. 3cm. The gradient coil stimulates the air in said air gap to vibrate and said vibration is transmitted respectively to the magnet shell and HF resonator.

III. The gradient coil is suspended concentrically in the opening of the magnet shell by means of carrier elements. Vibration of the gradient system is transmitted to the magnet shell via this mechanical support system. The HF coil is similarly suspended inside the vibrating magnet shell. This vibration is transmitted to the HF resonator.

In the prior art the transmission of vibration energy to the magnet shell or the HF resonator and noise emission via the magnet shell or via the HF resonator is counteracted by the use of mechanical and/or electromechanical vibration attenuators. Generally these are passive in action, e.g. rubber bearings, for piezo-actuators for example integrated in the gradient coil, which allow active counter control during controlled operation, thereby reducing the vibration amplitude of the gradient coil. Vibration of the magnet shell is generally attenuated by cushions against the gradient coil.

The following passive measures are generally also taken to reduce vibration:

- use of thick and heavy materials
- attenuation layers applied from "outside" (e.g. tar)

It is also known that this can be achieved by inserting sound-absorbing so-called acoustic foams in the area between the carrier tube and the gradient coil.

For example in published patent application EP 1 193 507 A2 the magnet shell of the basic field magnet is coated inside and outside with an acoustically attenuating foam mass and the front face is

also provided with noise-attenuating caps. Such encapsulation of the sound-inducing components of an MRT system in particular by means of an inherent shell structure is also disclosed in EP 1 077 382 A2, Patent Abstracts of Japan Vol. 1998, No. 03, 27 February 1998 - JP 09 299348 A and in the US patent US 5 084 676 A. The published patent application DE 198 38 390 A1 discloses an MRT device with a sound attenuation arrangement, by means of which the gradient field magnet system is encapsulated off from the patient. A similar encapsulation is set out in EP 0 350 640 A, whereby here the carrier tube holding the patient is extended axially beyond the gradient field magnet system and at the same time is expanded in a flared manner on both sides. Sound reduction of a different type is achieved according to Patent Abstracts of Japan, Vol. 2000, No. 11, 3 January 2001, JP 2000 232966 A by a special gradient coil design.

Nevertheless the acoustic emission of a current standard MRT device is still very high, particularly in the low frequency (50-200 Hz) range.

The object of the present invention is therefore to reduce further the noise transmission during operation of an MRT device in the entire relevant frequency range (50-2000 Hz) in a simple and economical manner.

This object is achieved according to the invention by the features of the independent Claim. The dependent Claims develop the central concept of the invention in a particularly advantageous manner.

According to the invention therefore a magnetic resonance tomography device is claimed that comprises a toroidal magnet body surrounded by a similarly toroidal magnet shell, which surrounds and defines an inner area in the form of a cylindrical area about the torus axis in the radial center of the magnet shell. The magnet

body is disposed in the toroidal inner area of the magnet shell and a gradient coil system arranged on a cylinder surface is disposed in the inner area and an inner encapsulation cylinder is disposed in the radial inner area of the cylinder surface. The magnet shell and the gradient coil system are externally and acoustically sealed off from the inner encapsulation cylinder and a capsule, which completely encloses the magnet shell in the radial outer area and is connected to the inner encapsulation cylinder in an acoustically sealed manner, whereupon acoustic vibrations, which are generated when the gradient coil system is switched and which are transmitted to the magnet shell, do not penetrate into the toroidal outer area, especially into the inner area,
characterized in that
the capsule represents a three-layer system, whereby the outermost layer comprises a cover layer, the center layer comprises a full foam layer and the inner layer comprises a partial foam layer containing foam patches or foam strips or the outermost layer comprises a cover layer, the center layer comprises a partial foam layer containing foam patches or foam strips and the innermost layer a full foam layer.

Both embodiments of the MRT device claimed according to the invention are acoustically identical. The first embodiment of the capsule has the advantage that a partial foam layer configured as the inner layer allows tolerance compensation, as a non-solid layer can adapt more easily to unplanned deformations in the magnet shell. The cover layer advantageously has a high mass per unit area.

Also advantageous is an inventive layer distribution in the capsule such that the full foam layer accounts for 2/3 and the partial foam layer 1/3 of the total layer thickness of the system.

One important aspect of the invention is that the surface fill

coefficient of the partial foam layer is up to 15% to 25% foam in the form of foam patches and/or foam strips. This takes the resonance of the capsule to below the acoustically relevant range (<50 Hz).

The width of the foam strips and foam patches is advantageously around 5cm.

For the purposes of heat dissipation, for example by natural convection, according to the invention the capsule has cutouts at suitable points.

According to the invention such a cutout comprises an air bridge in which foam strips with advantageously staggered offset toothing produce a labyrinth, through which air can penetrate but acoustic vibration is attenuated.

One further aspect of the present invention is that the inner encapsulation cylinder, the center of which, when viewed axially, comprises a cylindrical HF resonator, is extended overall by means of cylindrical carrier tube extension pieces in relation to the gradient coil behind when viewed radially, so that said carrier tube is longer than the gradient coil, whereby tongues are attached to the carrier tube extension pieces on the base side.

According to the invention the capsule is flange mounted in an acoustically sealed manner on the tongues and on the carrier tube extension pieces. A tapered expansion of the carrier tube extension pieces is thereby provided in the front area for reinforcing and optical purposes.

To reduce vibration further the outer ends of the carrier tube extension pieces are advantageously provided with reinforcing rings.

The original body coil carrier tube, the carrier tube extension pieces and the tongues form one section.

The outer ends of the tongues are also advantageously provided with reinforcing rings.

In a further embodiment of the invention, the tongues are also reinforced, whereby the additional reinforcement is achieved using further rails.

Further advantages, features and characteristics of the present invention are described in more detail below based on exemplary embodiments with reference to the accompanying drawings, in which:

Figure 1 shows a schematic section through the inventively encapsulated basic field magnet and the inventively modified components of the inner area surrounding it,

Figure 2 shows a section through the attenuating encapsulation at the interfaces with the inventively modified HF resonator,

Figure 3 shows the size ratios of the respective elements in relation to each other by means of a section through the attenuating encapsulation,

Figure 4 shows a top view of possible internal elements of the encapsulation,

Figure 5 shows a cross-section of a possible embodiment of a cutout,

Figure 6 shows the perspective view of an inventively modified HF resonator,

Figure 7 shows the perspective view of an HF resonator according to the prior art,

Figure 8 shows a schematic section through the basic field magnet and the components of the inner area enclosed by this according to the prior art,

Figure 9 shows a perspective representation of the basic field magnet,

Figure 10 shows a perspective representation of the gradient coil with the three part-windings.

The principal vibration source or vibration center - apart from the cold head - of a conventional MRT device according to the prior art, as shown for example schematically in Figure 8, is the gradient coil 2. The present invention allows noise transmission and noise emission, particularly in the low frequency range (50-200 Hz) to be significantly reduced by three measures or a combination of said three measures.

The measures are:

A) Encapsulation of the magnet shell and gradient coil using a cantilevered layer structure, the structural rigidity of which is less than that of the materials used,
B) Modification of the HF resonator and tongues configured as a body coil (BC),
C) Acoustically optimized configuration of cutouts in said inventive encapsulation.

The above inventive measures result in an inventively modified MRT device, as shown in Figure 1. The original cladding 29 is replaced by the novel encapsulation 22, which is connected at an

acoustically sealed interface 23 to the BC and encloses the entire magnet shell 12 with its upper and lower sections including the cold head 15 and gradient coil 2. The body coil (BC), originally comprising the cylindrical HF resonator 13 and contiguous tongues 30 in the lower section, has been extended by means of carrier tube extension pieces 31 overall - longer relatively than the gradient coil 2 behind it. The tongues 30 are shortened correspondingly.

The schematic structure of the encapsulation 22 in the area of the reinforcing rings 32 is shown in Figure 2. The capsule comprises three layers, an outer cover layer 26 of a material with a high mass per unit area, a first foam layer 25 of the softest possible full foam and a second foam layer 24 of foam strips and/or foam patches of the same material as the first foam layer 25.

The encapsulation 22 is cantilevered but its second foam layer 24 can for example be in contact with the magnet shell 12. This second foam layer 24 in combination with the first foam layer 25 and the cover layer 26 produces the structural softness of the entire encapsulation 22, which ensures that the resonance of said encapsulation 22 is at very low frequencies. This prevents an increase in noise in the acoustically relevant frequency range (i.e. > 50 Hz) compared for example with pure full foam encapsulation (as tested in the experiment). Such an overall structure 22 thus ensures noise reduction at low (50-200 Hz), average (200-500 Hz) and high (500-2000 Hz) frequencies.

The size distribution or size ratios of the individual components in the capsule 22 are shown in Figures 3 and 4. The first foam layer 25 accounts for 2/3 of the total capsule layer 22 and the

second foam layer 24 accounts for 1/3. The thickness of the cover layer is negligible. Overall the second foam layer 24 comprises only up to 15-25% foam material. This surface fill coefficient is achieved using foam patches or foam strips, as shown in Figure 4. The width D of such a foam strip or the side D of such a foam patch is approx. 5 cm.

If a conventional body coil (BC) according to the prior art, comprising the cylindrical HF resonator 13 and contiguous tongues 30 in the lower section (shown perspectively in Figure 7) is used with such an inventive encapsulation, the system still has noise weaknesses at the following points: the upper longitudinal ends of the cylindrical section 13 of the BC have relatively high vibration levels as do the tongues 30, which vibrate significantly due to their considerable length and softness despite two reinforcing rails 33.

According to the present invention the BC is therefore modified as follows (Figure 6 shows a perspective view):

The cylindrical section of the BC is extended by means of carrier tube extension pieces 31 so that it is longer overall than the gradient coil 2 behind it. According to the invention the resulting "inner encapsulation cylinder 13, 31" is made of a rigid, thick and heavy material. The tongues 30 are shortened correspondingly. For technical reasons relating to design, the front area of the cylindrical section is expended in a tapered manner and its outer ends are provided with reinforcing rings 32, on which the capsule 22 is flange-mounted in an acoustically sealed manner. The inventive increase in the number of stretcher rails to a total of four reduces the vibration by approximately the factor 3.

This inventive reconfiguration of the BC allows noise reduction to be achieved at the critical points for noise mentioned above, reducing the noise of the BC overall to a comparable level to that of the entire encapsulation surface.
Overall the invention achieves a reduction in vibration amplitude of the cover layer 26 compared with the vibration amplitude of the unencapsulated magnet shell 12 by the factor 30 in the overall acoustically relevant range (50-2000 Hz). This is measured with vibration sensors and directional microphones in proximity to the vibrating surfaces.

It is important with such encapsulation that the heat of all the heat-producing components inside the capsule (for example the electronic line at the side of the magnet shell 12) is dissipated to prevent overheating and associated failure. Therefore so-called cutouts have to be created at suitable points on the capsule 22 to allow convection inside so that the above-mentioned components can be cooled.

Such a cutout according to the present invention is shown in Figure 5. The inventive encapsulation 22 has a cutout point, which represents an air bridge. To prevent noise transmission at this point, graduated foam strips or foam strips with offset toothing 27 are arranged in the cutout, which attenuate the inward noise in an optimum manner.